Simulating Effects Based Operations

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ABSTRACT

Effects based operations (EBO) are proving to be a vital part of current concepts of operations in military missions and consequently need to be an integral part of current generation wargames. EBO is an approach to planning, executing and assessing military operations that focuses on obtaining a desired strategic outcome or "effect" on the adversary instead of merely attacking targets or simply dealing with objectives. Alternatively, the emphasis of conventional wargames is focused on attrition based modeling and is incapable of assessing effects and their contribution to the overall mission objectives. The focus of this paper is the integration of an EBO modeling scheme [1] within a force-on-force simulator. In this paper, the authors review the EBO modeling capability and describe its' integration within the wargame; including the integration of center of gravity (COG) models, the realization of indirect and cascading effects, the impact of the COG models on simulation control files, and the use of COG models to link the simulation commander with assets. A simple scenario demonstrating indirect and cascading effects is described and the results are presented.

Keywords: effects based operations; wargaming; military operations; center of gravity models; course of action

1. INTRODUCTION

The military planning process depends upon analysis systems to anticipate and respond in real-time to a dynamically changing battlespace with counteractions. Complex technical challenges exist in developing automated processes to derive hypotheses about future alternatives for mission scenarios. The military conducts combat operations in the presence of uncertainty and the alternatives that might emerge. It is virtually impossible to identify or predict the specific details of what might transpire. Current generation wargaming technologies typically execute a pre-scripted sequence of events for an adversary, independent of the opposing force actions. A significant research challenge for wargaming is predicting and assessing how friendly actions result in adversary behavioral outcomes, and how those behavioral outcomes impact the adversary commander's decisions and future actions. The focus of this research is to develop technologies to assist decision makers in assessing friendly courses of action (COAs) against an operational-level adversarial environment. Utilizing high performance computing (HPC) technology, it is possible to dynamically execute multiple simulations concurrently to evaluate COAs for critical elements related to execution and timing as well as overall effectiveness against a range of adversarial, or enemy COAs (eCOA) [2]. Conventional wargames are also insufficient when it comes to evaluating modern campaign approaches. They focus on traditional attrition based force-on-force modeling, whereas modern campaign strategies employ and evaluate a mixture of kinetic and non-kinetic operations. The Air Force is pursuing EBO as one such campaign approach [3]. EBO focuses on producing effects from military activities, as opposed to the direct result of attacking targets. For wargames to be effective, they must allow users to evaluate multiple ways to accomplish the same goal with a combination of direct, indirect, complex, cumulative, and cascading effects. The overarching objective of this research activity has been to address the challenges of simulating EBO COAs in the presence of a dynamic adversarial environment, faster than real-time. Such a system will allow planners to evaluate the effectiveness of today's alternative decisions and plans in tomorrow's battlefield.

2. RESEARCH PROGRAM

The current development activities include multiple research components: a simulation test bed, a scalable, flexible simulation framework; automated scenario generation techniques with dynamic update; intelligent adversarial behavior modeling; effects based/attrition based behavior modeling; and real-time analysis technology for comparing and grading

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14. ABSTRACT

Effects based operations (EBO) are proving to be a vital part of current concepts of operations in military missions and consequently need to be an integral part of current generation wargames. EBO is an approach to planning, executing and assessing military operations that focuses on obtaining a desired strategic outcome or "effect" on the adversary instead of merely attacking targets or simply dealing with objectives. Alternatively, the emphasis of conventional wargames is focused on attrition based modeling and is incapable of assessing effects and their contribution to the overall mission objectives. The focus of this paper is the integration of an EBO modeling scheme [1] within a force-on-force simulator. In this paper, the authors review the EBO modeling capability and describe its' integration within the wargame; including the integration of center of gravity (COG) models, the realization of indirect and cascading effects, the impact of the COG models on simulation control files, and the use of COG models to link the simulation commander with assets. A simple scenario demonstrating indirect and cascading effects is described and the results are presented.

15. SUBJECT TERMS

effects based operations; wargaming; military operations; center of gravity models; course of action

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effectiveness of alternative simulations. The architecture for the research program is depicted in Figure 1. The force structure simulation (FSS) test bed was developed in-house to provide a capability to demonstrate the associated technologies necessary for performing parallel COA simulations faster than real-time. The simulation framework will provide the foundation for rapid decision branch COA analysis [4]. Techniques to be able to evaluate multiple parallel COA simulations, as well as multiple branches, within a single COA are being developed. Automated scenario generation techniques will enable the dynamic creation of simulation input files to support the concept of multiple parallel COA simulations [5]. Research on techniques to model adversarial behaviors will provide a simulation capability to anticipate potential adversarial actions for dynamic adversary COA analysis. A generic modeling methodology was developed in-house to implement EBO concepts within virtually any modern wargame simulator. The generic EBO model is capable of mimicking arbitrary EBO COGs, which contain linkages and attributes of the target system. Techniques are also being investigated to define appropriate measures of effectiveness/measures of performance (MOEs/MOPs) for EBO COAs to help with the COA selection process.

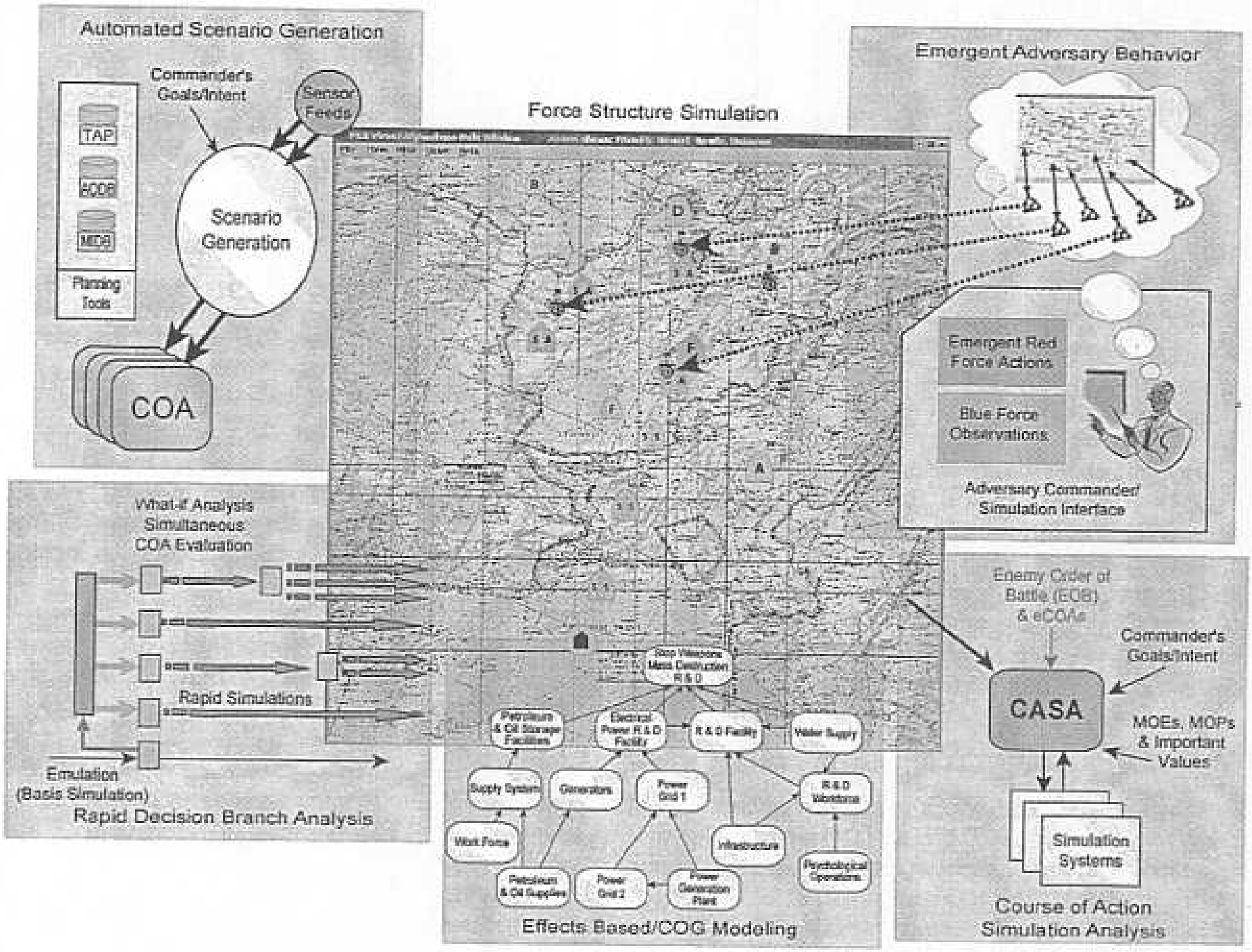

Figure 1. Real-Time Decision Support Architecture

This paper focuses on the integration of the EBO modeling capability within the FSS test bed. A review of the EBO modeling capability, which allows a user to create an arbitrary EBO COG model, will be presented first. One might envision a COG model as a set of nodes and weighted edges that describe a military force as a system of interdependencies. Military strategists rely on COG models when planning EBO campaigns, as the interdependencies are critical when utilizing a combination of direct, indirect, complex and cascading effects to accomplish military objectives. The discussion will then focus on the transformation and integration of the EBO modeling capability within the FSS test bed to fully realize an EBO COA analysis simulation capability. Since FSS is an in-house test bed, there is

flexibility to modify the simulation environment as necessary to evaluate and demonstrate ongoing research and development activities. FSS runs on the Synchronous Parallel Environment for Emulation and Discrete Event Simulation (SPEEDES) framework [6]. SPEEDES was chosen as the foundation for FSS because it helps exploit available high computational resources and provides much needed functionality. SPEEDES distributes and coordinates simulations across multiple central processing units of various HPC architectures, including workstations, clusters, or combinations of architectures.

To verify that the EBO modeling capability was successfully integrated within the FSS test bed, COA simulations of a simple scenario were performed. A scenario was developed that encompassed a simple COG model, which included complex and cascading node interdependencies. For comparison purposes, a simulation was performed on the same scenario; however, the interdependencies were removed from the COG model, resulting in a conventional force-on-force simulation. The results presented in this paper demonstrate the importance of COG modeling when performing EBO COA analysis.

3. INTEGRATING COG MODELS INTO FSS

The simulation of EBO in a wargaming environment has been accomplished through the integration of COG models [1] into the FSS testbed. The COG models described in [1] support indirect, cascading and complex effects, which are an essential characteristic of EBO.

The COG modeling methodology provides the framework necessary for simulating EBO concepts. One of the key EBO concepts is the cascading event. This simulation event represents the cascading nature of effects, which occur when a direct effect "ripples through an enemy target system, often influencing other target systems as well" [7], resulting in an indirect effect or outcome. In the wargame, this occurs when one simulation object is influenced by another simulation object that it relies upon. For example, if a factory is dependent on a power plant to function, then an event that causes the power plant to be disabled will cascade to the factory causing the factory to shutdown. A second essential EBO concept is the complex effect. This type of effect reflects the cumulative nature of effects. As described in [7], "cumulative effects result from the aggregate of many direct or indirect effects". For example, the production capability of a factory could be halted by destroying numerous transfer stations and generators, which are necessary for the power plant to function. A third key EBO concept is the center of gravity. COGs that are interdependencies of assets, such as the factory and the numerous transfer stations and power plants could be simulated in a force-on-force simulation that includes indirect and cascading effects. But not all COGS are an interdependency of assets. Some COGs can include more abstract concepts such as a "Work Force", or Leadership or morale.

To transform FSS from an attrition based force-on-force simulator to an effects based simulator, abstract COG elements such as morale and indirect and cascading events needed to be integrated within the simulation framework. To enable the simulation of indirect and cascading events, two new classes were required in FSS. The first class, "BaseCOG", controls the event scheduling, event handling, and logic for the simulation of effects based actions. The other class, "effects", is a data class that BaseCOG uses to determine how to process EBO events. Using the inheritance and polymorphism properties of object-oriented programming [8], capturing the ability to simulate indirect and cascading events was straightforward. The class diagram from the attrition based version of FSS is shown in Figure 2. FSS had two main types of simulation objects, assets and commanders, which allowed FSS to model and simulate attrition type force-on-force COAs. The addition of the BaseCOG and the effects classes to the FSS class structure resulted in a simulation capability for indirect and cascading effects. This is due to inheritance. The placement of the BaseCOG class above the assets and commanders classes in the class structure of the COG modeling methodology allows any simulation object to inherit from this class. And, since the BaseCOG class represents effects based properties, the inheriting classes will, as well. This class structure also allows the simulation objects to interact with any other simulation object. This interaction is necessary for representing the interrelationships inherent in COG models. The new class diagram is shown in Figure 3.

When FSS was an attrition based simulation, the class structure described in Figure 2 was suitable. Commanders would give scripts (orders) to assets, assets had a location, and assets would only attack other assets directly. Now that FSS is capable of simulating indirect and cascading events, the wargame needed to be expanded to model abstract concepts. For instance, if a commander wanted to wargame a COA to affect Troop A's morale, then the simulation would need to know Troop A's morale object type. A new simulation object was introduced into FSS, called AbstractCOG to allow for

abstract concepts, such as "World Opinion" to be modeled. The AbstractCOG can also represent an entity that is comprised of many locations, but could be modeled as one (e.g. Work Force). The AbstractCOG inherits directly from the BaseCOG, as shown in Figure 3, and it will have all the properties needed to implement EBO concepts, and will not be bounded by the constraints that an asset must follow.

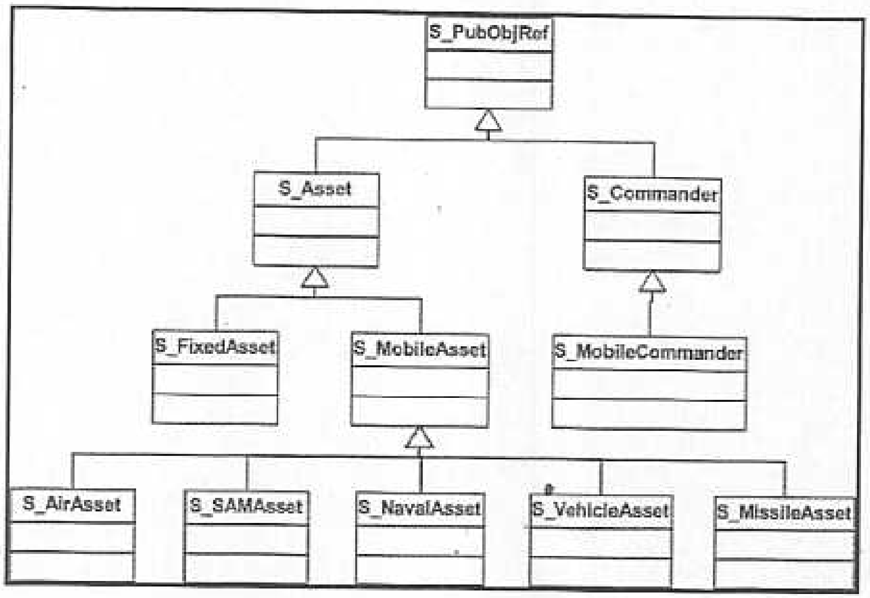

Figure 2. FSS Class Diagram Before the Introduction of EBO

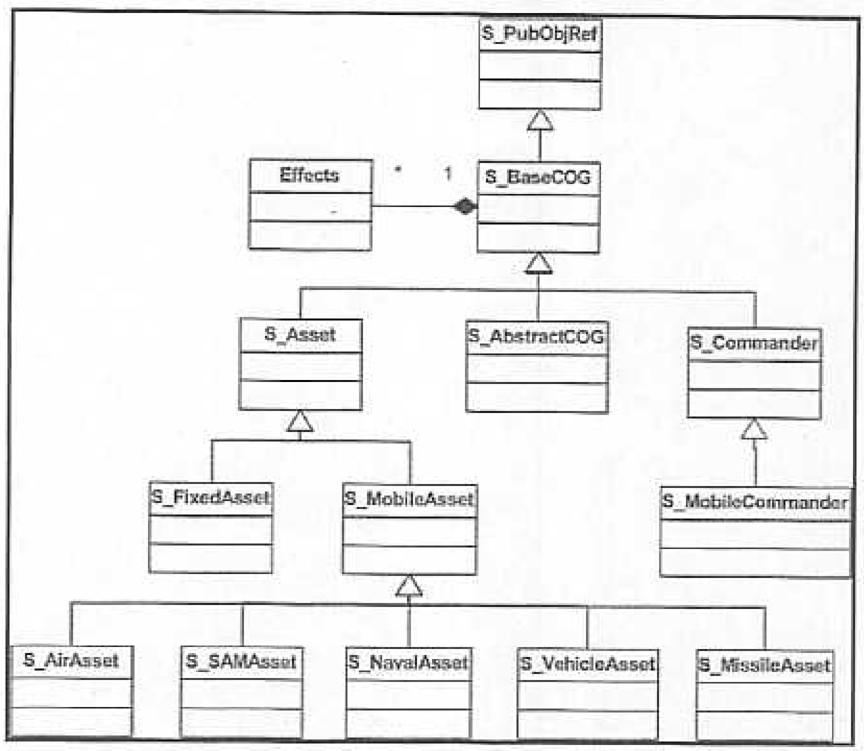

Figure 3. Class Diagram of FSS with EBO Capabilities

With the addition of the BaseCOG class to FSS to implement indirect and cascading events, came the requirement to be able to illustrate the status of the simulation objects. This is necessary to understand if the indirect, complex and cascading effects are being achieved. The current version of FSS has three possible states: available (fully operational), disabled, and destroyed. The COG modeling methodology allows for layers of indicators to reflect the possible states. There is a top level indicator, which reflects the overall status of the object. A top level indicator of a factory being affected could be: an inferred scan of the factory has detected no heat signatures from machines or people. There are also sub-level indicators, which illustrate if a cascading event had an affect on the object. An example of a sub-level indicator for a factory that has been affected might be that the work force is not present, evident by the employees' parking lot being empty during operating hours. For both levels of indicators, there is observable evidence to determine whether the object is operational or disabled.

The integration of the COG modeling methodology and the AbstractCOG class within FSS extends the simulation capability of FSS to encompass EBO concepts. This extension provides FSS with the capability of simulating direct, indirect, complex and cascading effects, which is more accurate and representative of current and future operations. Furthermore, FSS can provide several types of indicators, which provides a mechanism for the user to observe the current state of any simulation object, and the impact of the aforementioned effects. While FSS is capable of modeling abstract concepts such as "World Opinion", understanding how those concepts should be modeled and the impact of those concepts requires further research.

4. A SIMPLE SCENARIO

A simple scenario was created to exercise and demonstrate the concept of indirect and cascading effects that are intrinsic to EBO. This scenario was also used to demonstrate that COG models can be used to circumvent disturbing behavior in some simulations. The scenario can be defined by three parameter files: an assets file, a commander's file and a COG file. In this section the scenario is described, and the results of the simulations are presented and compared.

Some disturbing behavior can occur in FSS when assets that house commanders are destroyed. In FSS there are three types of simulation objects: assets, commanders and abstract COGs. Assets in the simulation execute missions which they receive from their commanders. However, within FSS, assets may only execute mission on other assets and not on their commanders. Suppose there is a commander at a blue Airborne Command Post, directing blue assets in an area of interest, and the red forces destroy the blue Airborne Command Post. The aircraft would be destroyed, but the commander would continue to provide scripted missions to its other assets. This behavior can provide an erroneous evaluation of the scenario being simulated. A mechanism that links a commander to an asset so that when the asset is destroyed, the commander stops functioning, would alleviate this situation and result in a much better simulation. Implementation of the COG dependency modeling mechanism overcomes this disturbing behavior.

Exploiting indirect effects and the COG modeling capability, it is possible to link a commander with an asset. This is accomplished by creating a dependency description that has the specified commander depending on the simulation asset, (a Command Post or an Airport). The effect of disabling the Airport or Command Post by engaging it with some assets, cascades into a disabling of the commander.

The geographical context of the simple, fictional, scenario is shown in Figure 4, where there are three red power plants, two red airports, a red bunker, and a blue battle group. The objective of the simple scenario is to demonstrate that the simulator supports direct, indirect, cascading and complex effects. This is achieved by disabling Airport 1 and two Air Defense Commanders, shown in Figure 5. Four aircraft are launched from the blue battle group to engage the red bunker and the three power plants. The red commander (Air Defense Commander 2) will deploy a Surface to Air Missile (SAM) asset, to engage the blue aircraft, unless complex and cascading effects disable the red commander.

Figure 5 shows the COG relationship for this simple example, which specifies assets and commanders. Air Defense Commander 2 depends on Airport 2, which in turn depends on the three power plants. Airport 1 depends on the two red commanders, Air Defense Commander 1 and Air Defense Commander 2. Air Defense Commander 1 is resident in Bunker ID_19 and is dependent on that bunker. The aircraft attack the bunker and then the power plants.

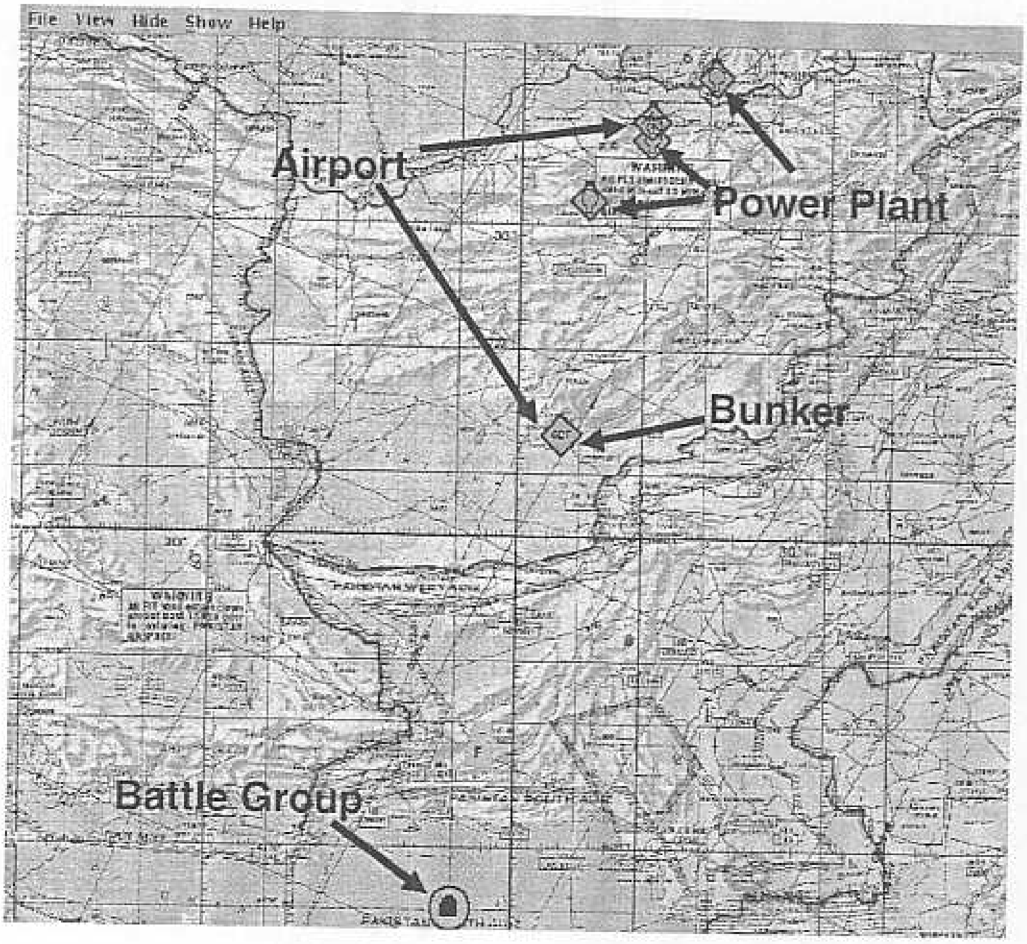

Figure 4. Simple Simulation Scenario

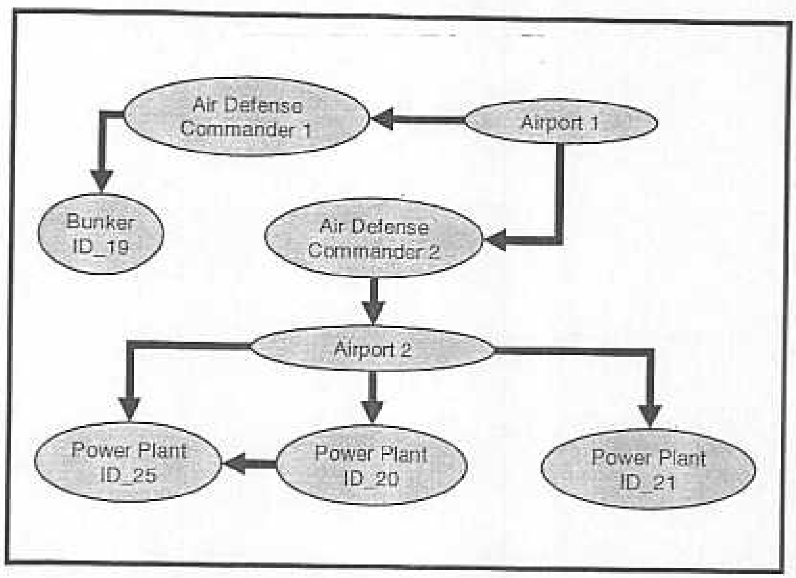

Figure 5. Simple Example of a Center Of Gravity

TIME (sec)	Symbol	Event Description
625	●	Launch Aircraft
4625	X	Engage Bunker ID_19; Bunker Destroyed
4950	⊗	Disable Air Defense Commander 1 **Cascading Event**
6400	X	Engage Power Plant ID_25; Power Plant Destroyed
6400	⊗	Disable Power Plant 20 **Cascading Event**
7050	X	Engage Power Plant ID_21; Power Plant Destroyed
7200	⊗	Disable Airport 2; Air Defense Commander 2; Airport 1 **Cascading Event**
7850	X	Engage Power Plant ID_20; Power Plant Destroyed
8400	R	Deploy SAM
8450	R	Engage Aircraft; Kill 2
9150	↑	Recovery of Power Plant ID_25
9200	↑	Recovery of Airport 2
9400	↑	Recovery of Air Defense Commander 2; Airport 1
9450	↑	Recovery of Power Plant ID_20
9600	↑	Recovery of Power Plant ID_21
11850	↑	Recovery of Bunker ID_19
12150	↑	Recovery of Air Defense Commander 1
17500	▲	Land Battle Group; 2 return (with COG four return)

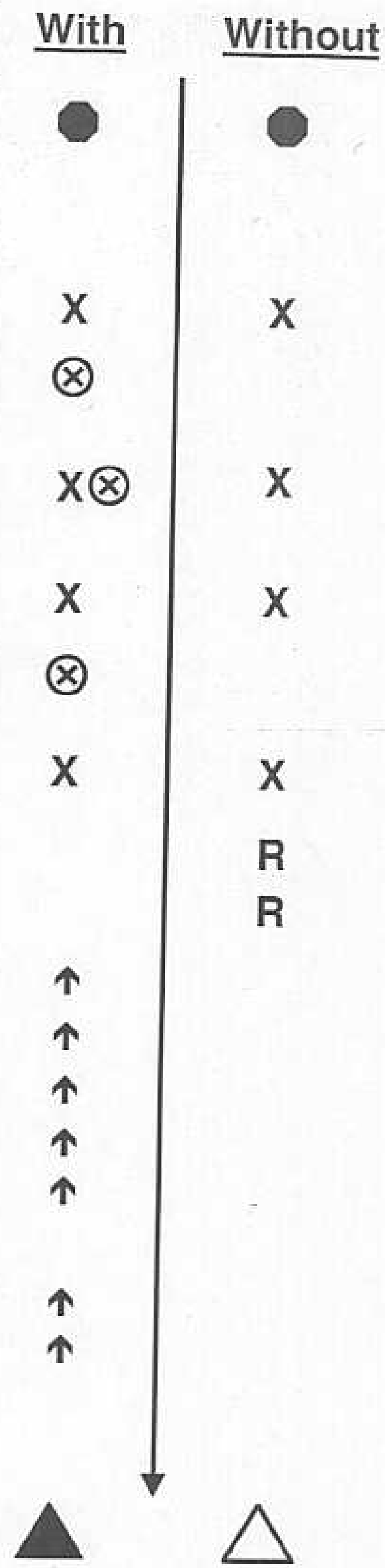

Figure 6 Time Line of Events in Simulation

The time line of events can be seen in Figure 6, where the events associated with the COG model are highlighted. In the scenario, aircraft are launched; they engage the bunker and the three power plants and return to the Battle Group. When simulated without a COG model, the bunker and power plants are destroyed, the SAM is deployed and engages the aircraft, two of which are destroyed. The other two aircraft return safely to the battle group.

When simulated with a COG model employed, the destruction of the bunker causes a cascading event to disable Air Defense Commander 1. The destruction of power plant 25 cascades to disable power plant 20. The destruction of power plant 21, cascades to disable Airport 2 and its commander, and results in the Airport 1 being disabled. Because Air Defense Commander 2 was disabled, the SAM was not activated, and all aircraft survive the mission.

Additionally, because the COG model includes recovery times for assets, the power plants, bunker, airports, and red commanders recover prior to the completion of the simulation. The timing of the recovery is determined by the specific recovery times and dependencies of the COG model. This is shown in Table 1 in the status and readiness columns.

Table 1 compares the end-state of the assets and commanders from this simulation with and without the use of the COG model. The grayed entries highlight that with the use of the COG model, all of the assets are available, and their status is set to 100. Without the use of the COG model, two aircraft are destroyed when the SAM asset is deployed. When the COG model is employed, all aircraft are available, as is the SAM, which was not deployed.

Table 1. Comparison of End State for Simulation (with/without) COG

ID	Asset Name	Status		Readiness	
		no COG	with COG	no COG	with COG
0	Air Defense Commander 1	100	100	available	available
1	Air Defense Commander 2	100	100	available	available
2	Battle Group	100	100	available	available
3	Airport 1	100	100	available	available
4	Airport 2	100	100	available	available
5	Power Plant ID_25	0	100	destroyed	available
6	Power Plant ID_21	0	100	destroyed	available
7	Power Plant ID_20	0	100	destroyed	available
8	Bunker ID_19	19	100	destroyed	available
9	Aircraft	43	100	destroyed	available
10	Aircraft	26	100	destroyed	available
11	Aircraft	100	100	available	available
12	Aircraft	100	100	available	available
13	SAM	100	100	deployed	available

5. SUMMARY

This paper described the first practical simulation of effects based operations in a wargaming environment. It presented and discussed the integration of a generic COG modeling capability into the FSS testbed. This COG modeling methodology supports indirect, cascading and complex effects, which are an essential characteristic of effects based operations. This capability enables next generation Concepts of Operations regarding EBO to be assessed and evaluated within a simulation environment in much faster than real time.

The efficacy of this methodology was demonstrated by exercising a simple scenario that included cascading and indirect effects which are so essential to EBO. This scenario, though relatively simple in nature, clearly demonstrates the innovative capabilities that are now an integral part of the FSS simulation framework.

REFERENCES

[1] McKeever, Gilmour, and Hillman, "An Approach to Effects Based Modeling for Wargaming", Proceedings of SPIE: International Society for Optical Engineering Enabling Technologies for Simulation Science VIII: DSS 2004, Orlando FL, April 2004.

[2] Surman, Hillman, and Santos, "Adversarial Inferencing for Generating Dynamic Adversary Behavior," Proceedings of SPIE: The International Society for Optical Engineering Enabling Technologies for Simulation Science VII: AeroSense 2003, Orlando FL, April 2003.

[3] Fayette, "Effects Based Operations." AFRL Technology Horizons®, vol 2, no 2, Jun 2001.

[4] Gilmour, Hanna, and Blank, "Dynamic Resource Allocation in an HPC Environment," Proceedings of the DoD HPCMP Users Group Conference, Williamsburg VA, June 2004.

[5] Koziarz, Krause, and Lehman, "Automated Scenario Generation," Proceedings of SPIE: The International Society for Optical Engineering Enabling Technologies for Simulation Science VII: AeroSense 2003, Orlando FL, April 2003.

[6] "Synthetic Force Structure Simulation", AFRL-IF-TR-2002-144 Final Technical Report, June 2002.

[7] US Joint Forces Command: Glossary, http://www.jfcom.mil/about/glossary.htm#C, February 2005.

[8] Page-Jones, "Fundamentals of Object-Oriented Design in UML" New York NY, Dorset House Publishing, 2000.